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Low Frequency Noise: A Major Risk Factor in Military Operations

Col. Nuno A.A. Castelo Branco, MD (PoAF, res.)
Center for Human Performance
Estrada Nacional No. 10, Edifício Cinema, Sala 109
2615 Alverca, Portugal
email: cph@mail.telepac.pt

Background. Noise is a major factor in many military environments. Usually the concern is with the higher frequency bands (> 500 Hz) that cause hearing damage or interfere with speech. Protection against noise is thus focused on these higher frequencies, while the bands of lower frequencies (< 500 Hz) are neglected, and non-audible bands, infrasound (< 20Hz) are ignored. In reality, long-term exposure to low frequency noise (<500 Hz, including infrasound) (LFN) can be quite detrimental to one's health. **LFN-Induced Pathology.** The disorders associated with occupational exposure to LFN have been described for aeronautical technicians and pilots. Diagnostic tools and methodologies for monitoring and controlling the development of LFN-induced pathology, have already been outlined. Immediate effects of LFN-exposure can include a) decreased capacity for cognitive functions, which implies a decline in performance, the consequences of which can be minor to devastating; b) sudden onset of acute respiratory problems, neurological disturbances, and mood alterations, such as, rage reactions. Cumulative effects of LFN-exposure can include triggering of early aging processes, and the development of vibroacoustic disease in susceptible (70%) individuals. Early compulsory retirement is a frequent situation.
Costs. Almost all military equipment require training programs for the operator. Long-term exposure to LFN can severely decrease the cost-return ratio for these operators, i.e., investment in training programs has little or no return. Accident/incidents can also damage the equipment itself, potentially jeopardizing missions. Waste of ammunition and other resources is another consequence of unmonitored LFN-exposed operators. The cost of ignoring LFN as an agent of disease is ultimately more expensive than the prevention, protection and, above all, selection of personnel for noise-environment positions.

INTRODUCTION

Noise is a major risk factor in many military environments. Noise is treated as a pollutant that can cause hearing damage and speech interference within the various vehicles and manned-stations. Thus, when protection against noise becomes an issue, the audible frequency bands (which coincide with those where speech occurs) are the focus of regulation and minimization.

Protection against noise is thus focused on these higher frequencies (>500 Hz), while the bands of lower frequencies (< 500 Hz) are neglected, and non-audible bands, infrasound (< 20Hz) are ignored [1]. This decades-old policy is based on an erroneous assumption: "Noise only affects the ear." This assumption pervades standard noise assessment procedures, the most blatant example of which is the use of the A-weighting system. This filtering system imitates human hearing, i.e., it de-emphasizes the lower frequencies and, naturally, ignores the non-audible infrasonic bands of acoustic phenomena [1].

In effect, when an acoustic environment is described merely in terms of dB(A), only the acoustic phenomena that can be perceived by the human auditory system is being evaluated. The acoustic environment may have significant components within the lower frequency

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bands, including the infrasonic range, and yet the acoustic energy contained within these bands is not taken into account. Why? Because they are not a major contributor to hearing impairment and speech interference.

On the basis of our 20 years of research on the effects of low frequency noise (LFN - ≤500 Hz, including infrasound), our team has learnt to regard LFN as an agent of disease (not just a pollutant), and to search for objective clinical indicators of LFN-exposure. LFN impinges upon an individual and it is irrelevant whether or not such acoustic phenomena is heard, or even perceived by the individual. X-rays are a perfect analogy: merely at a different frequency of electromagnetic radiation (or light), x-rays are not seen or perceived by the individual. Yet undue exposure to x-rays is a well-known health hazard. We propose that LFN be treated as x-rays, and thus human perception, i.e., annoyance, loudness, etc, are given the import of subjective measures.

VIBROACOUSTIC DISEASE

Long-term exposure to LFN can cause Vibroacoustic Disease (VAD): a systemic pathology, characterized by whole-body proliferation of the extra-cellular matrix [2-4]. VAD has been identified in military [5,6] and civilian pilots and aircrews [7], aeronautical mechanics and technicians [8,9], and, more recently, in a civilian population exposed to military training exercises for over five decades [10]. VAD is a whole-body pathology, simultaneously compromising several organ systems.

Decreased Cognitive Abilities and NeuroPsychiatric Pathology

In 1985, our group was awarded the first prize of the National Institute for Public Health, for the mathematical treatment of brainstem auditory evoked potentials (BAEP's) in a population of LFN-exposed workers [11]. Using clustering algorithms and multivariate analysis of the distribution of action currents, we successfully demonstrated that statistically significant differences existed in the P300 (longer latencies and lower amplitudes) and N2 (longer latencies) components of LFN-exposed personnel, when compared to controls [12]. These abnormalities are associated with cognitive deterioration. Brainmapping showed wave displacement that changed the potentials topography into frontal, often asymmetric, with multipeaked patterns, consistent with degenerative processes, and usually seen in the elderly. The average age of the LFN-exposed population was 42.7 years (range 31-57) [12].

In a subsequent MRI study of the same population, the following brain abnormalities were correlated with the existence of abnormal BAEP's: hyperintense foci in T2 of the subcortical and periventricular white matter, basal gânglia and brain stem – usually seen in Alzheimer's disease before signs of cortical atrophy; and cerebral atrophy and dilation of the perivascular Virchow-Robin spaces – also seen in dementia [12,13].

The memory quotient of individuals occupationally exposed to LFN, evaluated with the Weschler Memory Scale test, is significantly lower than that of the control population, although attention span, evaluated with the Toulouse-Piéron test, was not altered [14]. PACT – performance assurance computerized test, developed by ARCO, California, EUA after the Exxon Valdez accident, confirmed the cognitive deterioration in these individual [15,16].

Other neurological signs and disorders are frequently present in LFN-exposed individuals. Late-onset epilepsy was diagnosed in 10% of a group of LFN-exposed workers in an aeronautical plant in Portugal [17,2]. The expected rate in the general population is 0.2%. Epilepsy has also been seen in flight attendants [7] and in a automobile sales-clerk, whose office was housed in an unusual LFN environment [4]. A unique case among the literature of

vibration-induced reflex epilepsy has also been identified in an aeronautical technician [18,19] and now again in a flight attendant [in press].

Some LFN-exposed workers exhibit automatisms – non-purposeful movements reminiscent of an epileptic nature. Reports abound on aircraft technicians who walk in front of the turbine, thus being sucked in by the engines [2], or personnel on aircraft carriers who suddenly decide to walk off the deck into the water [20]. Our group believes this phenomena may be related to reported rage-reactions and unusual suicide attempts seen in LFN-exposed populations [4]. Mood disorders are among the first signs of VAD, and begin to appear after the first 1-5 years of LFN exposure [3]. These later progress into severe mood disorders such as depression, increased aggressiveness and irritation, especially when exposed to daily, urban noise [3,4]. Noise intolerance is a very frequent finding in LFN-exposed personnel and VAD patients [3]. Addiction-like phenomena can also be observed among these individuals. Frequently, retirees return to engine test sites to "be near the noise" that they "can't stand". Retired pilots, even those who retired with VAD-associated disabilities, move to urban locations directly in the pathway of approaching aircraft, to "hear the noise that they miss". This phenomena is most easily observable in the music and entertainment selections of the younger populations, which later may become candidates for military or civilian jobs involving additional exposure to LFN.

Balance disorders are also a common finding among LFN-exposed personnel. In 140 LFN workers, 80 complained of balance disorders [21], and in a group of 30 female flight attendants, 6 were on sick leave for severe balance disorders, among other, co-existing VAD-associated pathology [7]. In a group of 60 aeronautical technicians, 30 exhibited the palmo-mental reflex, an archaic reflex [22]. The existence of this reflex is an indication of diffuse cerebral dysfunction, and is normally seen in Parkinson's disease, multiple sclerosis and AIDS. The average age of this group of aeronautical technicians was, as above, 42.7 years, (range 31-57) [22].

Other VAD-Associated Pathology

In 1992, our group initiated studies with animal models, exposing rats to occupationally-simulated LFN exposure (8hrs/day, 5days/week, weekends in silence). As a result of electron microscopy studies, it was discovered that the respiratory system is a major target for LFN [23-28] (Fig.1,2,3). In LFN-exposed human populations, repeated infections of the oropharynx, bronchitis (even in non-smokers), and atypical cases of pleural effusion were frequently observed [29]. Focal lung fibrosis was identified in the LFN-exposed animal models, and later confirmed through high resolution CT Scan in LFN-exposed, non-smoker workers [30].

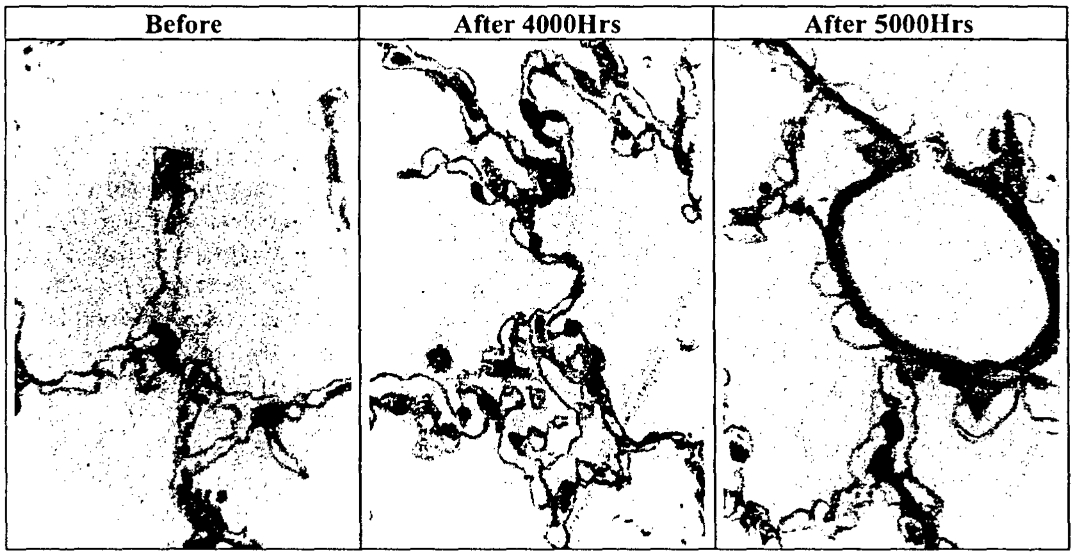

FIG 1 - Histology of rat lung: normal (left), LFN-exposed for 4000h (center), and LF N-exposed for 5000h (right). (Orig. mag. x800)

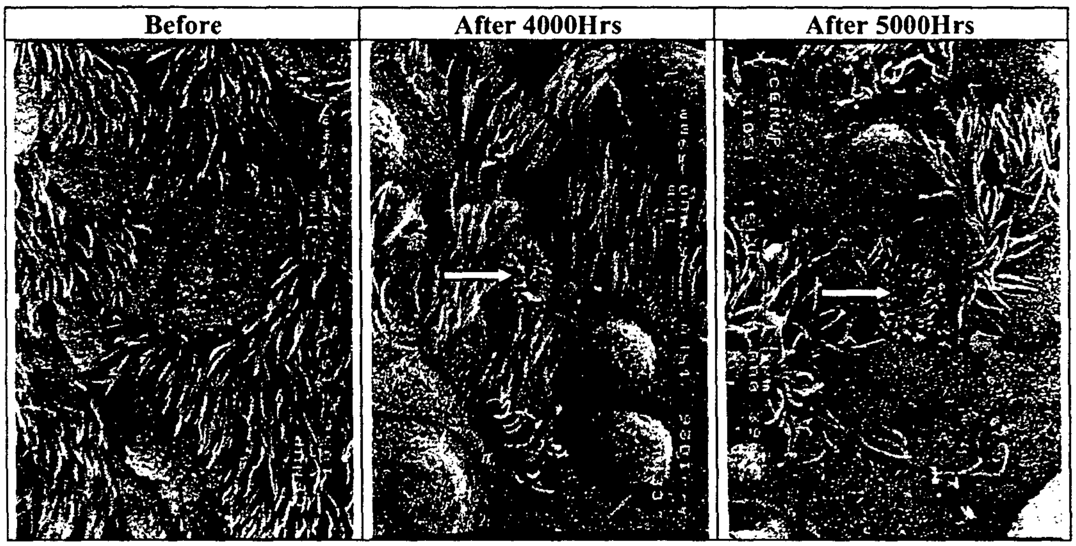

Fig 2 - SEM of small brochioli: normal (left), LFN-exposed for 4000h (center), LFN-exposed for 5000h (right). Arrows indicate indentations in brush cells. (Orig. mag. x5000)

Before	After 4000Hrs	After 5000Hrs

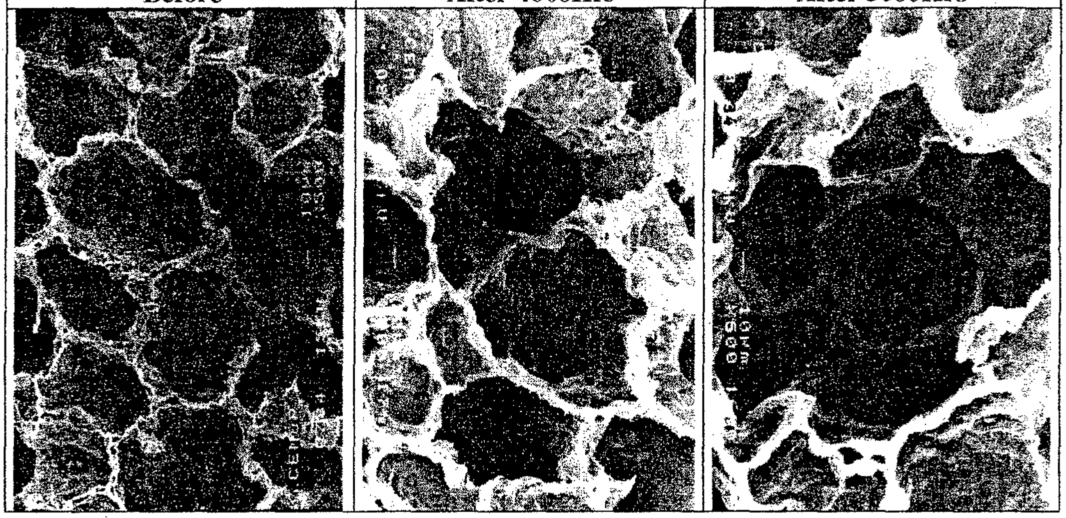

Fig 3 - SEM of lung parenchyma: normal (left), noise-exposed for 4000h (center), noise-exposed for 5000h (right). (Orig. mag. X500)

Cardiovascular pathology has been one of the most significant LFN-induced situations. Thickening of the pericardium is the hallmark of VAD and LFN-exposure [31, 32], although a generalized cardiovascular thickening exists throughout the LFN-exposed organism (Fig 4). It should be noted that unlike the typical thickening due to atherosclerotic plaques, LFN-induced cardiovascular thickening is like a continuous blanket, covering the walls of the vessel [6,33,36]. Echo-imaging of thickened pericardia, aortic and mitral valves, and carotid arteries are readily visible, and have made the echocardiogram the method of choice for screening for previous LFN exposure [7-10].

Normal	18 Years of occupational exposure

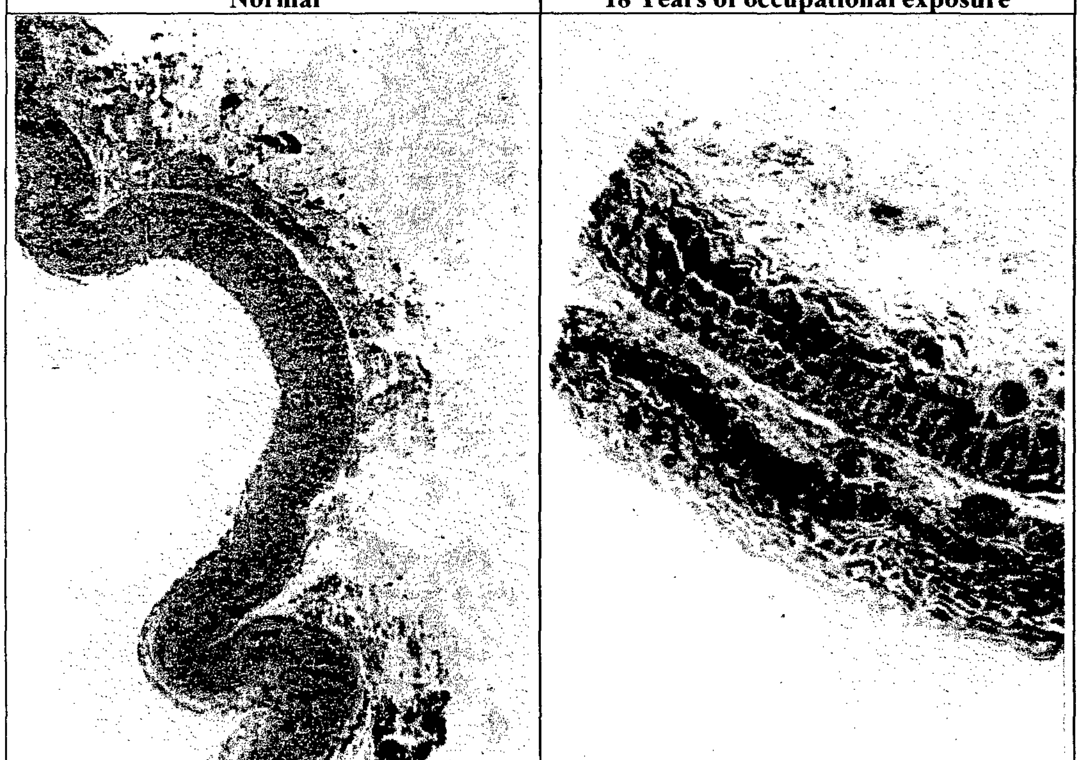

Fig 4 - Light microscopy of a normal pericardium from a 51-year-old male (Orig. mag. x100).	Light microscopy of the pericardium of a 39-year-old VAD patient (Orig. mag. X100).

The genotoxic component of LFN has already been demonstrated in both animal [37] and human models [38,39] through the increased frequency of sister chromatid exchanges in LFN-exposed populations. Malignancy among VAD patients has been increasingly well characterized. LFN-induced lung tumors are only of one type: squamous cell carcinoma. In the central nervous system, only glial tumors have been found. Other tumors are all located in hollow organs: bladder, colon, larynx and kidney [2].

Immunological studies have also been conducted on both human and animal models, and have shown that LFN modulated the immune system. In LFN-exposed workers, the amount of circulating CD8+ and CD4+ T lymphocytes was significantly altered [40]. In mice prone to developing lupus erythematosus, LFN-exposure accelerated the autoimmune kidney disease [41] and changed the lymphocyte subpopulation in the spleen [42]. Lupus is a common observation among LFN flight attendants [7] and other LFN-exposed populations [10].

Cumulative Effects, Recovery Periods and Individual Susceptibility

The effects of LFN-exposure are cumulative, and do not discriminate between sources. Acoustic phenomena within the lower frequency bands, including infrasound, can be generated by a variety of sources: ship or aircraft engines, weapons systems, manned vehicles, by jetskis, rock concerts, motorbikes, danceclubs, car audio systems, public transportation, high volume highways, etc. By being exposed to one or more of these sources, daily, cumulative effects of LFN exposure settle in and pathology is established.

Adequate recovery periods are fundamental to minimize LFN-induced damage. However, as should be expected, recovery periods are not linear. The silence-period required for reversibility of tracheal lesions induced by 48 hrs of continuous LFN exposure is 7 days [43]. Recovery periods for other LFN exposure patterns are under study.

Throughout all the studies with human populations, a consistent 30% of the individuals did not develop severe cases of VAD. Instead, discrete VAD-associated pathology would appear, however none would evolve to severe stages [3]. In a study conducted on airline pilots, the older pilots had less pericardial thickening than many of the younger pilots [7]. It is believed that this is due to survivorship bias: the older pilots are less susceptible to LFN. Studies are underway to confirm this hypothesis. Possible physiological indicators of individual susceptibility are also understudy. Early disability retirement is a frequent occurrence among LFN-exposed personnel [4].

Other Studies

Our group is not the first to describe this set of signs and symptoms in noise-exposed workers. In the Detroit Ford aircraft engine plant, in the 1940's, Dr. Dart was the first to identify an extra-aural, noise-induced pathology [44].

In the 1960's, the effects of LFN on the human respiratory system, suggesting that this system is very sensitive to noise, inducing severe coughing, gagging sensation and chest pressure after exposure of minutes to frequencies < 100 Hz, at > 100 dB [45, 46]. Dogs were used in another study which also showed the lungs to be particular susceptible to LFN: 3 mm pulmonary lesions, that do not increase in size with increased exposure, but instead increase in number [47]. Rumancev also in the 1960's studied workers in factories producing reinforced concrete, and described many of the symptoms today associated with VAD [48]. In the 1970's Cohen and Anticaglia published 2 studies that strongly supported the notion of a noise-induced, extra-aural pathology [49,50], and the inefficacy of hearing conservation programs on extra-aural pathology. Again, the symptomatology today associated with VAD is described in boiler plant workers [49].

In 1983, Matoba *et al.* was the first to describe pericardial thickening in noise-exposed workers [51]. Currently, Drs. Nekhoroshev and Glinchikov in St. Petersberg, Russia conduct microscopy animal studies, after exposure to single tones of LFN [52,53], verifying much of the same cellular pathology that our group has also seen.

COSTS

Most military equipment and weapons-systems require extensive and costly training programs for the operator. Most often, the work environment of the operator is pervaded by LFN, which is not assessed during standard noise measuring procedures for the reasons given in the beginning of this report. By not monitoring for LFN-induced pathology, the operator can develop severe stages of VAD without being diagnosed. The consequent risk is not trivial and should not continue to be ignored.

In addition to the possibility of human casualties, accident/incidents can damage the equipment itself, potentially jeopardizing missions. Waste of ammunition and other resources is another consequence of unmonitored LFN-exposed operators. Incorrect operation of weapons-systems can lead to a decreased operational lifetime, or even to very premature retirement of the entire unit. The possibility of rage-reactions, increased aggressiveness and irritability, all in added to noise intolerance, are hardly desirable conditions for military operators. Epileptic seizures and automatisms are also quite undesirable, especially within a military scenario. Long-term exposure to LFN can severely decrease the cost-return ratio for these operators, i.e., investment in training programs has little or no return, because operators' operational lifetime is severely decreased.

Screening and monitoring procedures for LFN-exposed personnel are cost-effective. Screening young candidates to LFN positions for pre-existing LFN exposure proved successful in an aeronautical plant. By excluding young men who already exhibited thickening of cardiac structures (due to previous LFN exposure) from LFN jobs, and by removing workers who exhibited severe stages of VAD from their LFN work environments, the number of early disability retirements dropped from 21 (1980-1989) to zero (1989-1996) [54].

The cost of ignoring LFN as an agent of disease is ultimately much more expensive than implementing prevention, protection, and selection procedures among personnel working in noise-environment positions. Monitoring LFN-exposed personnel could halt the cognitive deterioration in these individuals, prolonging their time on active duty, and avoiding the possibility of early disability retirement.

The most serious situations occur where LFN generation is continuous, and no possibility of "quiet" time (or recovery period) exists. Such is the case of ships, submarines, tanks, space vehicles, and long-haul aircraft. Often, personnel must remain within a LFN environment, usually an already confined space, for months at a time. Considering that mood disorders, increased aggressiveness and irritability, in addition to cognitive deterioration, are initial signs of VAD, there should be a vigorous effort to afford LFN-exposed personnel some protection. The most dramatic situation of LFN environments is in Space. Here there is no external damping to dissipate the LFN generated by life-support systems and other such equipment, onboard space vehicles. More importantly, in the case of an accident/incident, return to a "quiet" location may not be immediate. The importance of selection procedures for individuals who will be exposed to LFN is crucial for the success of long-term missions.

Auricle protectors will aggravate the effects caused by impinging LFN. Referring back to the x-ray analogy, auricle protectors for LFN is analogous to dark glasses for x-ray protection – they are inadequate. The problem with protection against LFN is the long wavelength of acoustic phenomena within the lower frequency bands. As a rule of thumb, the size of audible noise protectors are proportional to the acoustic phenomenon's wavelength. For example, the

wavelength of a pure tone at 4000 Hz (frequency at which professional deafness is decided) is 8.5 cm, at 1000 Hz it is 34.3 cm, at 500 Hz it is 68.6 cm, at 100 Hz it is 3.43 meters, at 20 Hz it is 17.1 meters, and at 5 Hz it is 68.6 meters. Clearly, physical protection against LFN is not yet feasible. In Pensacola, Florida, the U.S. Department of the Navy is researching new materials that can reduce LFN. They have achieved an impressive 30 dB reduction at 80 Hz, however implementation of this material in real-world scenarios is still not underway. Nevertheless, protection can be afforded, today, to LFN-exposed personnel by monitoring the progression of VAD using echocardiography. It is important to note that among aeronautical mechanics and technicians, those who regularly wore their auricle protectors suffered worse cases of VAD [S]. This is because the auricle protectors allowed them to remain within the LFN environment for much longer periods of time than their non-auricle-user co-workers.

It is not surprising that LFN, including infrasound, was investigated in order to develop weapons. LFN is an ubiquitous agent of disease, especially in the military. Our group urges physicians in charge of LFN-exposed personnel to establish and implement prevention and protections programs against LFN exposure and the development of VAD. It will be worth the fight!

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Reference # of Paper: Invited Lecture # 3
Discusser's Name: Dr. D. G. Zimcik
Author's Name: Col. Nuno A. A. Castelo Branco, MD
Question:

Results presented on the human effect of low frequency noise (LFN) are startling and seem to be missed by current standards for acceptable noise used in many countries. What changes are planned or underway in regulations to include these effects?

Answer:

As far as we know, no changes to current legislation are planned or underway with two exceptions: Puerto Rico, where a Jan 2001 law limits the emission of LFN; and Mozambique, where preparations for a new law includes LFN. Permissible exposure levels for LFN, the necessary recovery times for each type of exposure period, and dose-response data are unknown. These are necessary for human exposure legislation. Individual susceptibility indicators are under study by our group: but, as yet, there is insufficient data.